PTO 06-3423

Kokai Patent Application
No. Hei 7[1995]-266073

LASER MACHINING DEVICE

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UNITED STATES PATENT AND TRADEMARK OFFICE
WASHINGTON, D.C. MARCH 2006
TRANSLATED BY THE MCELROY TRANSLATION COMPANY

JAPANESE PATENT OFFICE
PATENT JOURNAL
KOKAI PATENT APPLICATION NO. HEI 7[1995]-266073

Int. Cl.^{6}:	B 23 K 26/12 H 01 L 21/302
Filing No.:	Hei 6[1994]-79815
Filing Date:	March 25, 1994
Publication Date:	October 17, 1995
No. of Claims:	5 (Total of 5 pages; FD)

LASER MACHINING DEVICE

[Reeza kako sochi]

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[There are no amendments to this patent.]

Claims

1. A laser machining device characterized in that in a laser machining device in which a workpiece is placed in a vacuum chamber, and a UV laser is used to machine said workpiece,

it is provided with a magnetic field generation means that generates magnetic gradient that is directed from the inner area to the outer area of the aforementioned workpiece while becoming lower toward the radiation source of the aforementioned UV laser.

2. The laser machining device described under Claim 1, characterized in that the aforementioned magnetic field generation means is provided with a magnetic field convergence means that focuses a magnetic field toward a machining position.

3. A laser machining device characterized in that in a laser machining device in which a workpiece is placed in a vacuum chamber, and a UV laser is used to machine said workpiece,

it is provided with a magnetic field generation means that generates magnetic gradient that is directed from the inner area to the outer area of the aforementioned workpiece while directed toward the radiation source of the aforementioned UV laser and

a magnetic field application means that applies a DC field in the direction the aforementioned workpiece is machined.

4. The laser machining device described under Claim 3, characterized in that the aforementioned magnetic field generation means is provided with a magnetic field convergence means that focuses a magnetic field toward the aforementioned machining position.

5. The laser machining device described under Claim 2 or 4, characterized in that the aforementioned magnetic field generation means is provided with a pulsed magnetic field generation means that superimposes a pulsed magnetic field with magnetic gradient similar to the aforementioned magnetic gradient in sync with the radiation of the aforementioned UV laser.

Detailed explanation of the invention

[0001]

Industrial application field

The present invention pertains to a micromachining technique that utilizes a UV laser beam to realize laser abrasion in order to machine a workpiece. In particular, it pertains to a laser machining device that is used to create minute trench holes at a high aspect ratio.

[0002]

Prior art

When finer trenches are to be created on ceramics and a metallic material, lateral propagation of heat from the machining position poses a problem. Thus, in the recent years, machining utilizing a UV laser is gaining attention. The reason is that it is believed that unlike fusion and sublimation using an IR laser, the energy one photon carries in its wavelength area is several *ev* or so, and because the photon acts directly on the level of electrons in the solid, it results in a heatless process. More specifically, it is believed that positive ions and electrons lunge out to let the machining progress as the outermost electrons of the atoms (molecules) in the solid, which are responsible for coupling, are ionized due to the absorption of said photons. It is feasible to remove the substance to be machined by taking notice and advantage of this phenomenon. If possible, removal of scrapings, which are thought to be difficult to remove from the bottom of the holes machined during what is called high-aspect-ratio-machining, especially when a depth 10 or more times as much as an opening diameter is involved, from the workpiece can be achieved, so that the aspect ratio can be improved better than ever.

[0003]

Accordingly, the applicant of the present invention already submitted an idea that a DC field is applied parallel to the direction machining is advanced, and the particles scraped and ionized positively during the machining are pulled out using said electric field applied after the radiation of the laser in Japanese Kokai Patent Application No. Hei 5[1993]-120816.

[0004]

Problems to be solved by the invention

However, in order to realize the ionization efficiently at the part where the laser is radiated, the electrons have to be pulled out of the workpiece first. However, the aforementioned preceding patent application does not include any mechanism to remove said electrons efficiently, resulting in a problem in terms of post-machining active removal of the fine particles that presume ionization. In addition, Japanese Kokai Patent Application No. Sho 61[1986]-37391 is also available as another prior art. In this case, a magnetic field is applied to a workpiece parallel to a laser beam for the purpose of achieving smooth finishing of the machined surface by restraining the interaction between a plasma generated and the machined surface after the laser is radiated. However, said patent pays no special consideration to gradient of the magnetic field applied, nor does it include any concept of actively restraining the dynamic behaviors of the plasma generated. Thus, it does not aim to achieve high aspect ratio machining by any means.

[0005]

Accordingly, in light of the aforementioned problems, the objective [of the present invention] is to present a laser machining device by that effective laser machining can be realized in order to allow high aspect ratio machining.

[0006]

Means to solve the problems

Accordingly, the present invention aims to achieve an operation to pull out the electrons ionized by the laser radiation mainly utilizing magnetic gradient and an operation to actively discharge the positive ions as scrapings created as a result of the machining to the exterior at the same time. As such, in order to solve the problems, the configuration of the present invention is characterized in that in a laser machining device in which a workpiece is placed in a vacuum chamber, and a UV laser is used to machine said workpiece, it is provided with a magnetic field generation means that generates magnetic gradient that is directed from the inner area to the outer area of the aforementioned workpiece while becoming lower toward the radiation source of the aforementioned UV laser. In addition, the configuration of a related invention is characterized in

that the aforementioned magnetic field generation means is provided with a magnetic field convergence means that focuses a magnetic field toward a machining position.

[0007]

The configuration of the second invention is characterized in that in a laser machining device in which a workpiece is placed in a vacuum chamber, and a UV laser is used to machine said workpiece, it is provided with a magnetic field generation means that generates magnetic gradient that is directed from the inner area to the outer area of the aforementioned workpiece while directed toward the radiation source of the aforementioned UV laser and a magnetic field application means that applies a DC field in the direction the aforementioned workpiece is machined. The configuration of the second invention is further characterized in that the aforementioned magnetic field generation means is provided with a magnetic field convergence means that focuses a magnetic field toward the aforementioned machining position.

[0008]

Furthermore, the magnetic field generation means is characterized in that the aforementioned magnetic field generation means is provided with a pulsed magnetic field generation means that superimposes a pulsed magnetic field with magnetic gradient similar to the aforementioned magnetic gradient in sync with the radiation of the aforementioned UV laser.

[0009]

Operation

As magnetic field gradient is created at the part of a workpiece where a laser spot is radiated using a magnetic field generation means provided on the back surface side of they workpiece, and an additional magnetic field convergence means, if needed, the intensity of the magnetic field becomes weaker toward the outside. The workpiece is exfoliated and becomes a plasma at the atomic level as a result of the laser radiation, and electrons and ions are created as scrapings steadily at the machining position. Because they usually have kinetic energy, the receive a force toward the outside due to the magnetic field gradient, so they are removed from the machining position immediately.

[0010]

Effect of the invention

Because the condition in which the machining position is exposed to the laser beam constantly without any residual machining scrapings can be maintained, the machining depth can

be increased; and because efficient machining can be realized, the machining speed can be improved, so that fine machining at a high aspect ratio can be realized.

[0011]

Application examples

The present invention will be explained below based on specific application examples. Figure 1 is a diagram showing the condition in which target material to be machined (workpiece) 1 is being machined in the laser machining device of the present invention, and it is carried out under the setting shown by the outlined configuration diagram in Figure 2. Workpiece 1 is placed inside vacuum chamber (vacuum chamber) 3, that is made of quartz glass and provided with laser penetration window 2 as shown in Figure 2. Because laser beam 4 is radiated to the workpiece in the form of a slim beam, and it ends up spreading before it reaches the workpiece, it is radiated through quartz lens 5 and laser penetration window 2 and regulated so as to increase the energy density, so that it will be focused at a position on the front surface of the workpiece. Furthermore, although it is not shown, a lens-hoisting means or a lens-exchanging means should be utilized in order to allow the focal position of lens 5 to be changed as needed. Moreover, an auxiliary electromagnetic removal means may also be provided so as to prevent the charged particles removed from the machining position from hitting the laser penetration window in order to keep the efficiency of the laser beam from dropping.

[0012]

Plate material 6 is spread not very thickly, preferably 1 mm thick or so, over the back surface of workpiece 1, and permanent magnet 8 (or electromagnetic coil) serving as a magnetic field generation means is provided below it via yoke 7 serving as a magnetic field convergence means made of a ferromagnetic material such as iron or ferrite. It is desirable that plate material 6 be strong enough to support workpiece 1, and that it be made of a magnetically transparent nonmagnetic material. Yoke 7 is focused so as to achieve roughly 1/100 of the magnetic pole surface area of magnet 8 in terms of area ratio at the back surface (back surface where the laser is not radiated) of the sample, and it is placed directly below the laser radiation position.

[0013]

Due to said magnetic field gradient, the lines of magnetic force 9 become the densest at the bottom part of the machined hole, and they become scarce gradually toward the exit of the machined hole. That is, lines of magnetic force 9 are present in the direction parallel to the incident direction of laser beam 4, and magnetic field gradient 10 is present further from the bottom part of the machined hole toward its exit. Due to said magnetic field gradient 10, the

positive ions and the electrons are discharged toward the outer side of the machined hole where the lines of magnetic force are scarce while they are turning in circle (in helical motions) in the respective directions as they both receive Lorentz force. As a result, the probability of the electrons ionized, after being irradiated by the laser, lunging out toward the outside of the workpiece becomes greater than the probability of them returning toward the workpiece, so that ionization at the radiation position can be facilitated. In addition, the ionized fine particles are also discharged actively from the machined hole toward the outside due to magnetic field gradient 10. In addition, because the ionized electrons engage in the helical motions around lines of magnetic force 9, collisions of the electrons with the machined sidewall can be restrained, resulting in an effect that a thermal damage to the sidewall can be reduced also. As a result, machining at a higher aspect ratio and with less thermal damage than ever can be realized.

[0014]

Second application example

In order to make the improvement, that is, create magnetic field gradient 10 so as to discharge the charged particles using Lorentz force as is the case in the aforementioned first application example, magnetic flux B and spatial gradient gradB play respective roles in terms of physical quantities. Thus, it is also feasible to determine them independently so as to realize the optimum magnetic field assignment. Figure 3 shows such an application example. Yoke made of a ferromagnetic material such as iron is placed below workpiece 1 via plate material 6 with its contact part concentric with plate material 6. Field coil A 12 is wound around the core part of yoke 11, the area at the front end part of the yoke is narrowed down and placed directly below the machining part. Coil B 13 with a coiling diameter while wound in the same direction as the direction coil A 12 is wound is placed in the space between the core part of yoke 11 and the peripheral part. The density of magnetic flux B and its gradient gradB can be controlled by controlling the values of currents applied to coils A and B. Furthermore, the configuration in Figure 3 is merely an example, a configuration in which S pole is placed at a higher position than N pole, or the other way around, in terms of the shape of yoke 11 may be adopted as a modification example. Furthermore, an electric circuit (ferromagnetic material, second magnetic field generation means) may be provided above the workpiece as a part of the aforementioned magnetism [sic; magnetic field] generation means in order to correct the magnetic gradient appropriately.

[0015]

Third application example

In addition, an application example in which weak electric field 14 is superimposed in order to facilitate the discharging of the electrons in particular is shown in Figure 4. The magnetic field application means comprises a set of opposite electrodes to that voltages are applied so as to charge the workpiece. In this case, weak electric field 14 is formed by giving a high potential to workpiece 1 between electrode plate 15 and plate material 6. While the direction of said weak electric field 14 is the direction for the electrons to be accelerated toward the exit of the machined hole, although the positive ions are less likely to be decelerated due to the large mass, their discharging speed is decreased in this direction nonetheless. Thus, a weak electric field that will not interfere with the discharging of the positive ions is used. The reason is that because the electrons have a small mass, the electrons can be discharged with a minute electric field value. Because said value changes depending on the depth of the machined hole and the material used, a prescribed value should be used according to the situation to be dealt with. Due to said electric field 14 and magnetic field gradient 10, the electrons exfoliated by the laser are discharged while turning in circle, and the probability that they are discharged toward the side where the magnetic field gradient is scarce increases, so that the intended machining can be realized. Because the electrons have a small mass, they are discharged before the positive ions, and many positive ions remain at the machining area. As a result, the discharging of said positive ions from the machining part can be facilitated as they act repulsively against each other and move toward the outside of the workpiece where the magnetic field gradient is mild.

[0016]

Fourth application example

In addition, as another configuration, as shown in Figure 5(a), a pulsed magnetic field with sharp magnetic field gradient at the bottom part and the exit of the machined hole is generated in a magnetostatic field formed by permanent magnet 8 and yoke 7 in sync with the pulsing radiation by the laser and superimposed on said magnetostatic field. The pulsed magnetic field is generated by pulse coil (pulsed magnetic field generation means) 16. Pulse coil 16 is provided so as to surround workpiece 1, wherein the coil wire is wound more densely toward the bottom part of the workpiece in order to create gradient intensity inside thereof. Electric charges stored in a condenser are applied momentarily to said coil. As a result of the superimposition of said pulsed magnetic field, intensity curve of the magnetic field moves toward the upper part of the hole. A condition in which the pulsed magnetic field is superimposed is shown in Figure 5(b). Although the plasma essentially has a tendency to move from a part where the magnetic field is dense to a part where it is scarce, said parallel movement of the magnetic field potential curve

itself increases said trait, so that the plasma generated by the radiation from the laser can be discharged from the exit of the hole even more effectively.

[0017]

Although a large quantity of ionized particles is created at the machining position by the laser radiation in all of the application examples, because the particles created are present at the machining position steadily as the laser radiates continuously, a machining [method] in which the laser is radiated in pulses in order to radiate the laser newly so as to generate new particles after most of the charged particles are discharged once may be adopted, and the pulse drive for the alternate removal of the residues may be realized using a program. In addition, a gas supply means for supplying a reactive gas to the machining position of the workpiece may also be provided as needed.

[0018]

Any solid material can be used as the target workpiece as long as it absorbs the energy of the laser, so that its application in a wide range can be expected. However, because the magnetic gradient is hard to create when the target workpiece is a magnetic material, it cannot be used as a target workpiece.

Brief description of the figures

Figure 1 is a diagram for explaining operations of the configuration of a first application example of the present invention.

Figure 2 is an overall configuration diagram of Figure 1.

Figure 3 is an outlined configuration diagram showing a second application example.

Figure 4 is an outlined configuration diagram showing a third application example.

Figure 5 are an outlined configuration diagram showing a fourth application example and a diagram showing the characteristic of its magnetic field.

Explanation of symbols

1	Workpiece (material to be machined)
2	Laser penetration window (quartz glass)
3	Vacuum chamber (vacuum chamber)
4	Laser beam
5	Lens
6	Plate material
7	Yoke (magnetic field convergence means)

8 Permanent magnet (magnetic field generation means)
9 Lines of magnetic force
10 Magnetic field gradient
11 Yoke (magnetic field convergence means of second application example)
12 Coil A (magnetic field generation means)
13 Coil B (magnetic field generation means)
14 Weak electric field
15 Electrode plate (magnetic field application means)
16 Pulse coil (pulsed magnetic field generation means)

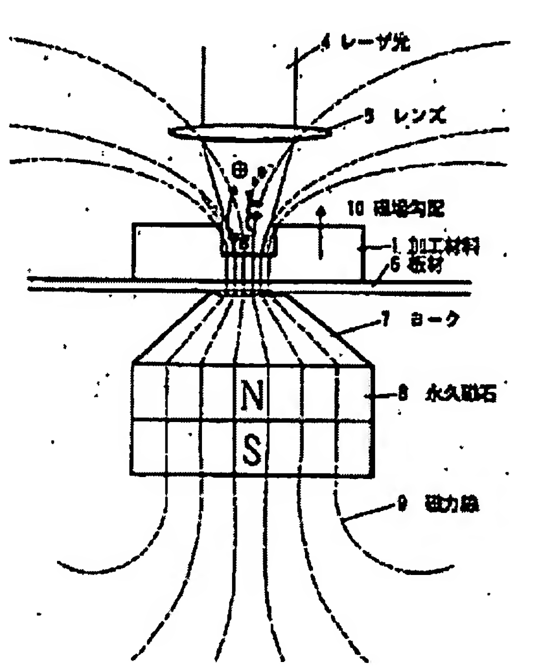

Figure 1

Key:
1 Workpiece
4 Laser beam
5 Lens
6 Plate material
7 Yoke
8 Permanent magnet
9 Lines of magnetic force
10 Magnetic field gradient

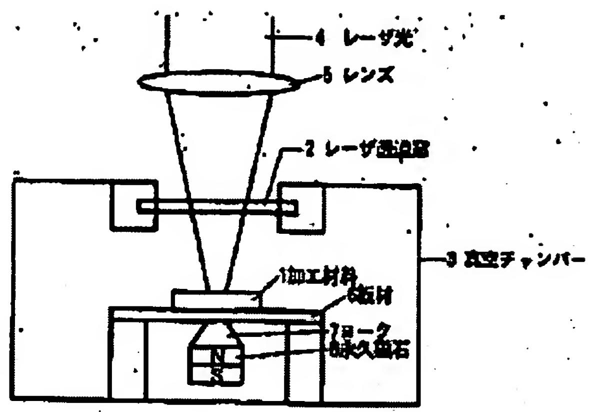

Figure 2

Key: 1 Workpiece
2 Laser penetration window
3 Vacuum chamber
4 Laser beam
5 Lens
6 Plate material
7 Yoke
8 Permanent magnet

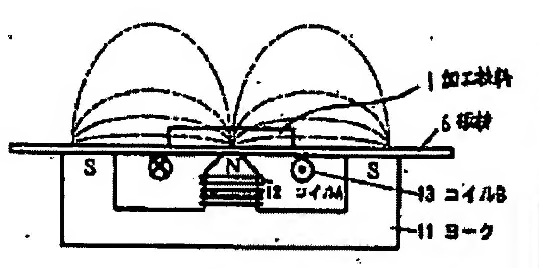

Figure 3

Key: 1 Workpiece
6 Plate material
11 Yoke
12 Coil A
13 Coil B

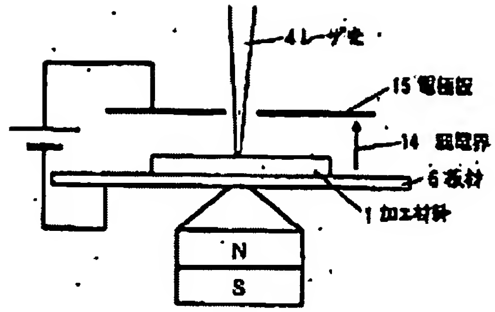

Figure 4

Key:

Key:	1	Workpiece
	4	Laser beam
	6	Plate material
	14	Weak electric field
	15	Electrode plate

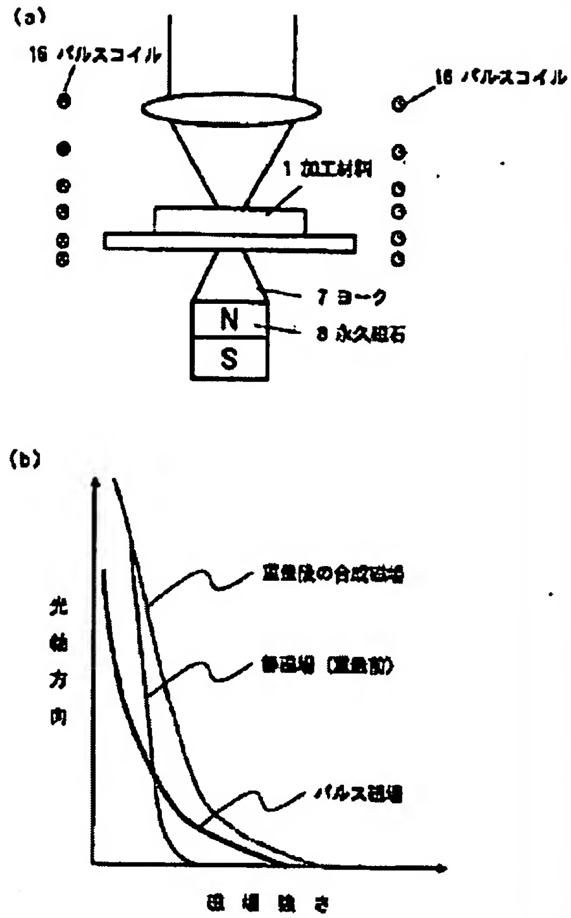

Figure 5

Key:

A	Direction of optical axis
B	Composite magnetic field after superimposition
C	Magnetostatic field (before superimposition)
D	Pulsed magnetic field
E	Intensity of magnetic field
1	Workpiece
7	Yoke
8	Permanent magnet
16	Pulse coil